



## Technologies For Removal Of Arsenic From Water: An Overview

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### Abstract

*Arsenic contamination in drinking water is a major global issue. Arsenicosis may be caused due to chronic consumption of arsenic contaminated water. Economic and convenient removal of arsenic from water has remained a terrific challenge. Most commonly employed technologies for arsenic removal from water are coagulation and flocculation, filtration, membrane separation, ion exchange, adsorption to name a few. Nanotechnology has potential to play an important role in providing clean water for human utilization. Solar oxidation and removal of arsenic (SORAS) is a very simple technique to bring down arsenic content from the contaminated water.*

**Keywords:** Oxidation, coagulation and flocculation, precipitation, ion exchange, membrane separation, adsorption, SORAS

### 1. INTRODUCTION

Groundwater is one of the most crucial natural resources for domestic, industrial as well as agricultural water supply. The natural occurrence of arsenic in groundwater is one of the biggest problems in providing safe drinking water globally (The World Bank, 2005). Arsenic is one of the most toxic elements in the environment and causes the highest number of morbidity and mortality worldwide (Cullen and Reimer, 1989; Dermatas et al., 2004; Hudson-Edwards et al., 2004). According to World Health Organization, the permissible limit for arsenic is 10 µg/L in drinking water and 0.10 mg/L in irrigation water (Bhattacharya et al., 2009; Ahsan and Del Valls, 2011). Many Asian countries including India, China, Myanmar, Pakistan, Vietnam, Nepal, and Cambodia have been found to have arsenic concentration beyond permissible limits. In India, the extent of ground water arsenic contamination in West Bengal has reached an alarming condition as nine districts of West Bengal have been reported to have ground water arsenic concentrations above 50 µg/L and several people have been affected by arsenic poisoning (Chakraborti et al., 2009). Excessive and long-term human intake of toxic inorganic As from drinking water and food may result in arsenicosis, which results in skin disorders, skin cancers, internal cancers, diseases of the blood vessels of the legs and feet, possibly diabetes, increased blood pressure, and reproductive disorders.

Several natural and anthropogenic sources have been found to be responsible for arsenic contamination in groundwater. The main anthropogenic sources include mining, burning of fossil fuels, use of fungicides, herbicides and insecticides in agriculture and wood preservatives.

### 2. TECHNOLOGIES FOR ARSENICAL REMOVAL

Arsenic removal technologies should be such that they do not cause any adverse effect on the environment. Extensive research has been carried out to identify new technologies for arsenic removal. The presence of high concentration arsenic contaminated water sources can be analyzed in two distinct stages. The first stage consists of finding safe alternative sources with very low or no arsenic concentration that in addition show acceptable physical-chemical and bacteriological quality. The second stage consists of adopting for arsenic removal considering the presence of arsenite in the water source. The judicious selection of the most adequate alternatives should be based on a cost-benefit analysis conducted for each of the possible removal techniques. Coagulation-filtration and softening with lime addition techniques have been found to be cost effective but are less efficient processes. Among the efficient techniques (with efficiency >95%), adsorption using aluminum carbonates have been found to be cost effective (USEPA, 2001). Application of hybrid adsorbent can also be considered for arsenic removal because it is environment friendly as well as cost effective. Despite its effectiveness, the use of membranes for arsenic removal significantly increases the cost; hence it becomes unsustainable for small water supply systems. Research has also been carried out for the improvement of existing conventional technologies such as adsorption (Siegel et al, 2006; Mohan and Pittman, 2006) by modifying or using novel adsorbent materials (Pena et al, 2005; Boddu et al, 2008), or by introducing new chemical oxidation processes.

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## 2.1 Physical-Chemical Technologies

Most of these technologies rely on the oxidation of arsenite followed by filtration through a porous material, where arsenic is removed through adsorption and co-precipitation.

TiO<sub>2</sub> immobilization, combined with co-precipitation of arsenic on iron (III) hydroxides (oxides), could be a competent approach for removal of inorganic arsenic from water (Fostier et al, 2008; Mendes et al, 2009). Because of their very strong affinity for arsenic, iron compounds are used by many removal systems. Recently research was carried out to come across a suitable iron to arsenic ratio in water to reduce arsenic to 5 ppb (or lower) through slow sand filtration. It was found that a ratio of 40:1 was necessary to ensure the desired arsenic concentration in the treated effluent (Pokhrela and Viraraghavan, 2009).

### 2.1.1 Oxidation

Arsenic occurs in groundwater as arsenite, As(III) and arsenate, As(V). Most of the arsenic treatment technologies are effective in removing arsenate, but the removal efficiency of arsenite is very low. Therefore, some treatment technologies include oxidation as a pre-treatment step to convert As(III) to As(V). In developing countries, atmospheric oxygen, hypochlorite and permanganate are commonly used for oxidation of arsenic. Some other chemicals such as gaseous chlorine, ozone and other oxidizing agents can also been used, which are capable of oxidizing rapidly.

### 2.1.2 Coagulation-flocculation

Coagulation is a conventional water treatment method, used effectively for arsenic removal. In this method, coagulants (e.g. alum or ferric chloride) are added with rapid mixing, which results in the formation of micro-flocs. This is followed by gentle stirring for a few minutes (flocculation) resulting in the formation of larger settleable flocs. During the coagulation-flocculation process, arsenic also gets attached to the flocs. Subsequently, sedimentation and filtration (co-precipitation) are used to separate the flocs.

A three-step treatment process involving mild alkaline pH-conditioning by NaHCO<sub>3</sub>; oxidation of arsenite and ferrous ions by KMnO<sub>4</sub>, self-precipitation as insoluble MnO<sub>2</sub> under the pH condition; and coagulation by FeCl<sub>3</sub> has been used for simultaneous removal of arsenic and iron ions from water. The process removes iron, arsenic as well as other heavy metals, if present, without leaving any further toxic residue. (Bordoloi et al., 2013)

The method based on Oxidation-Coagulation-adsorption at Optimized pH (OCOP) using NaHCO<sub>3</sub>, KMnO<sub>4</sub> and FeCl<sub>3</sub> as pH conditioner, oxidant and

coagulant, respectively, is a competent and low-cost method for removal of arsenic from groundwater which has been gaining recognition in India. In this method, a high dose of the oxidant is used when the groundwater contains high concentration of coexisting iron for oxidizing all ferrous and arsenate ions. A field trial at different arsenic affected rural areas showed that the modified OCOP method is more efficient and reasonably priced than the OCOP method reducing both arsenic and coexisting iron concentrations. (Bora et al., 2016).

### 2.1.3 Coagulation-flocculation-precipitation followed by filtration

Ferric chloride is a preferred coagulant (Hu et al, 2012; Garcia et al, 2012; Zhnag et al, 2012) due to its availability, low cost and low risk usability (Hering et al, 1996). Arsenate and arsenite can form surface complexes with iron hydroxide sites in co-precipitated and adsorbed solids (Meng et al, 2000).

In electrocoagulation, electric current is used to generate metallic ions. The ions generated during the process polymerize rapidly and form precipitates with high affinity for arsenic (Mohora et al, 2012; Genuchten et al, 2012). Electrocoagulation is a promising approach and has gained much awareness for arsenic removal (Gomes et al, 2007; Balasubramanian et al, 2009; Kobya et al, 2011; Lacasa et al, 2011; Flores et al, 2013).

## 2.2 Membrane-Based Processes

Membrane techniques like reverse osmosis, nanofiltration and electrodialysis are capable of removing all kinds of dissolved solids including arsenic from water. In this process, water is passed through special filter media, capable of physically retaining the impurities in water. The oxidation from arsenite to arsenate is essential for carrying out nanofiltration and reverse osmosis. In a typical Donnan dialysis process, separation is based on ion exchange membrane. This ion exchange membrane separates two solutions (feed and stripping solutions) and excludes co-ions (ions with the same electrical charge as the ion exchange membrane) from permeating the membrane. Therefore, the flux of a counter-ion (ions with the opposite electrical charge to the ion exchange membrane) through the membrane caused by a concentration difference is always coupled with the transport of identical numbers of counterions in the opposite direction to maintain the electroneutrality in both solutions (Sarkar et al, 2010). Anion-exchange membranes are required to remove arsenic from the feed solution and an anionic counterion (most of the times chloride) has to be present in the stripping solution. Several Donnan-dialysis based arsenic removal processes have been tested and they have demonstrated the feasibility and ease for implementation (Zhao and Zhao, 2010; Velizarov, 2013).

Membrane distillation is another innovative technology based on membranes, which has been studied for arsenic removal. This process is based on a non-conventional technology and can be a feasible alternative to water with high arsenic content. The process operates in the temperature range of 40-80 °C and can be powered by heat generated from waste processes or low grade renewable heat sources (Yarlagadda, 2011). The arsenic removal rates of over 99.7% have been reported (Qu et al, 2009; Manna et al, 2010; Pal and Manna, 2010), which is much better than other reported membrane filtration techniques like nanofiltration and ultra-filtration (Zwijnenberg et al, 2012).

### 2.3 Ion Exchange

Ion exchange is very effective when As(V) is predominant in water, otherwise a pre-oxidation step is necessary. Arsenic removal is done by passing water under pressure through columns packed with strong-base anion (SBA) exchange resin. These resins are insensitive to pH in the range 6.5 to 9. The exchange affinity of ions depend on their net surface charge. Therefore, the efficiency of the anion exchange process for As(V) removal depends on the concentration of other anions such as sulfate and nitrates. Synthetic ion exchange resins are used in water treatment to remove undesirable ions. Various anion exchange resins, capable of removing arsenic (arsenate) concentration below 1 mg/L are commercially available.

High Efficiency Ion Exchange for Arsenic Removal treatment system is a commercially available technology capable of removing arsenic to non-detectable levels in drinking water. It can also removing other harmful contaminants such as, nitrates, perchlorate, uranium, chromium VI, and vanadium to non-detectable levels.

### 2.4 Adsorption

Adsorption is evolving as an effective method for removal of contaminants from water. Modern activated carbon industrial production was established in 1900–1901 to replace bone-char in sugar refining. Powdered activated carbon was first produced commercially from wood in Europe in the early 19th century and was widely used in the sugar industry. Activated carbons have been prepared from coconut shells, wood char, lignin, petroleum coke, bone-char, peat, sawdust, carbon black etc. Adsorption capacity depends on activated carbon properties, adsorbate chemical properties, temperature, pH, ionic strength, etc.

The low cost adsorbents can be obtained from various sources. Some of the commonly used low cost adsorbents include agricultural wastes, industrial wastes, biomass, human hairs, chitin and chitosan,

commercial adsorbents and biosorbents. Agricultural wastes are by-products, currently unused or underused for animal feed. Agricultural waste/by-products such as rice husks were used for arsenic removal from water (Khalid et al, 1998).

Red mud has been explored as an alternate adsorbent for arsenic removal. Heat and acid treatments on red mud increased its adsorptive capacity. Arsenic adsorption on acid and heat treated red mud is also pH dependent (Altundogan et al., 2002).

A large number of commercial adsorbents are now available for the removal of As(III) and As(V). The fungus, *Penicillium purpurogenum*, has been examined for cadmium, lead, mercury, and arsenic removal from water (Ridvan et al. 2013).

Chitosan powder derived from shrimp shells, was converted into beads and used for removal of As(III) and As(V) from water in both batch and continuous operations (Chen and Chung, 2006). Biomass derived from the stem of *Acacia nilotica* has been investigated to remove As ions from surface water samples of different origins like lake, canal and river (Baig et al. 2010). The effects of various parameters viz. pH, biosorbent dosage, contact time and temperature on the biosorption processes were studied. The percent removal of As increased up to 95% when the dosage of biosorbent material was increased from 0.4 to 4 g/L, whereas further increase in biosorbent material dosage up to 20 g/L have no effect on the percent removal of As. The increase in biosorbent material dosage (0.4–4 g/L) resulted in a rapid increase in adsorption of As ions.

Iron is by far the most recurrent metal present in the sorbents. Iron oxides and oxy-hydroxides have been reported as effective sorbents for arsenic removal (Bowell, 1994). Some prepared iron oxide based sorbents are commercially available and have been successfully employed for arsenic removal (Oti et al, 2012). More advanced and sophisticated options include nanotechnology for the production of nano-composites. Arsenic removal by zero-valent iron (ZVI) is a distinguished process based on the adsorptive properties of the compounds generated by the corrosion of ZVI in water (Lackovic et al, 2000; Lien and Wilkin, 2005; Calo et al, 2012; Ye et al, 2012; Eslamian et al, 2013).

The removal of arsenic from water by zeolites is well-reported (Shevade and Ford, 2012; Misaelides et al, 2011) but more recent efforts have been focused on modifying their surface properties. Among all the possible alternatives for these modifications, the use of surfactants has gained application (Li et al, 2007; Yusof et al, 2009; Mendoza-Barrón et al, 2011; Swarnkar and Tomar, 2012).

Titanium dioxide based materials are well-known for arsenic photocatalytic oxidation and adsorption but some future needs for this technology have been proposed, including the reduction of the treatment cost, the decrease in the operational complexity of the technology or the disposal of the arsenic-bearing treatment wastes (Guan et al, 2012).

## 2.5 Biological Technologies

Biological processes can play an important role in enhancing many of the chemical processes. Biological and microbiological methods have been found to be environmental friendly and cost effective for arsenic removal. Two major biological mechanisms can describe the reduction of arsenate into arsenite. The first mechanism is related to the detoxification of the cells. Arsenate ions enter the cells via phosphate transporters due to structural homologies with phosphate ions. After reaching the cytoplasm, As(V) is reduced into As(III) by the enzyme *ArsC* before being excreted from the cell (Mukopadhyay and Rosen, 2002). The second process, known as dissimilatory reduction, has been described in bacteria belonging to various phylogenetic groups including obligate or facultative anaerobic micro-organisms (Paez-Espino et al, 2009). Biosorption is capable of removing traces of heavy metals and other elements from dilute aqueous solutions. It is important to differentiate biosorption or sorption from bioaccumulation.

Biosorption (or bioadsorption) is a passive immobilization of metals by biomass. Mechanisms of cell surface sorption are independent of cell metabolism; they are based upon physicochemical interactions between metal and functional groups of the cell wall. The microorganism's cell wall mainly consists of polysaccharides, lipids and proteins, which have many binding sites for metals. This process is independent of the metabolism and metal binding is fast. Bioaccumulation, in contrast, is an intracellular metal accumulation process which involves metal binding on intracellular compounds, intracellular precipitation, methylation and other mechanisms. Bioaccumulation can also be regarded as a second part of the metal sequestering process by living biomass. Sometimes, it is called active biosorption as the opposite to passive biosorption. Since it depends on the cell metabolism, it can be inhibited by metabolic inhibitors such as low temperature and lack of energy sources. Metal uptake by dead cells takes place by the passive mode. Living cells employ both active and passive modes for heavy metal uptake. Fungi are used in many industrial fermentation processes, which could serve as an economical adsorbent for arsenic removal. Fungi can also be easily grown in substantial amounts using unsophisticated fermentation techniques and inexpensive growth media. Lignin has also been used for the metal ions remediation.

The biological oxidation of As(III) to As(V) by iron and manganese oxidizing bacteria has been reported and it was also confirmed that As(III) can be mitigated without any additional use of chemicals (Casiot et al, 2003).

Anaerobic microorganisms play an important role in the release of arsenic in iron-rich aquifers, where arsenic is typically sequestered by iron minerals. New developments in the biotechnological field have focused on phyto-remediation and biofiltration processes (Katsoyiannis and Zouboulis, 2004; Murugesan et al, 2006) that have revealed to be efficient and environmentally sustainable. In phyto-remediation, plant and fungal biomass are used as a renewable adsorbing material in a process that is similar to chemical compound removal. The adsorbing capacity of this biomass is superior to that of activated carbon and of some synthetic resins used in water treatment.

The application of biological processes for the removal of arsenic from water is an emerging field that shows a great potential mainly because it is an environmentally compatible treatment option (Lasat, 2002). Biological activity can remove arsenic by various different mechanisms such as sorption, biomethylation–demethylation, complexation, coprecipitation or oxidation–reduction processes. Besides, a diversity of organisms shows potential for its application for arsenic removal, including bacteria (Fukushi et al, 2003; Zouboulis and Katsoyiannis, 2005) fungi (Tani et al, 2004), yeasts and algae (Shen et al, 2012; Sulaymon et al, 2013; Hansen et al, 2006; Kumar and Oommen, 2012), lichens (Sari and Tuzen, 2010), plants (Lasat, 2002; Huang et al, 2004; Dickinson et al, 2005; Cherian and Oliveira, 2005) and complex biological communities as constructed wetlands (Arroyo et al, 2013; Buddhawong et al, 2005; Lizama et al, 2011; Llorens et al, 2013) or even waste biomass (Teixeira and Ciminelli, 2005; Czerniczyniec et al, 2007).

Constructed wetlands have been employed extensively around the world during the last decades for improving water quality, including the removal of heavy metals. The main removal pathways of As in constructed wetlands are biologically-mediated precipitation, co-precipitation and sorption, but the importance of plants and microorganisms present in the medium also needs to be assessed (Zurita et al, 2012).

Biological methods are efficient in treatment of arsenic contaminated waters but, until now, most biotechnological treatments for arsenic removal have only been investigated in laboratory studies under well-defined conditions. Further full-scale demonstrations are required to demonstrate their technical viability in more complex real systems and the corresponding cost-effectiveness analysis need to be conducted to assess their applicability (Wang and Zhao, 2009).



Wasiuddin et al., 2007 examined the ability of human hairs to adsorb arsenic from contaminated drinking water. Both static and dynamic tests along with the numerical modeling have been carried out to test human hairs as an adsorbent. The maximum adsorption capacity of 12.4 g/g was reported at an arsenic concentration of 360 g/L.

The ability of *Garciniacambogia* to remove trivalent arsenic from solution has been studied and found that the kinetic property and uptake capacity of fresh biomass are significantly enhanced by immobilization. The uptake of As(III) by fresh and immobilized biomass was not greatly affected by solution pH with optimal biosorption occurring at around pH 6–8 (Kamala et al., 2005).

A biosorbent was prepared by coating ceramic alumina with the natural biopolymer, chitosan, using a dip-coating process. Removal of Arsenic(III) and Arsenic(V) was studied through adsorption on the biosorbent at pH 4.0. The adsorption capacity of the sorbent is 56.50 and 96.46 mg/g of chitosan for As(III) and As(V), respectively. The difference in adsorption capacity for As(III) and As(V) was explained on the basis of speciation of arsenic at pH 4 (Boddu et al., 2008).

The sorption property of the Shelled *Moringa oleifera* seeds (SMOS) for decontamination of arsenic from water bodies was explored. Maximum sorption for As(III) and As(V) species was 60.21% and 85.60%, respectively (Kumari et al., 2014).

Study has been conducted for the removal of As(V) on bone char in batch as a function of pH, adsorbent dose and contact time. Uptake of As(V) ion by bone char was rapid in the first 30 min and equilibrium time was independent of initial As(V) concentration. The duration of arsenic adsorption was kept 30 min, optimum adsorption was achieved in the pH range of 9 to 13 (Chen et al., 2008).

The biosorption characteristics of As(III) and As(V) from aqueous solution using the macrofungus (*Inonotus hispidus*) biomass were investigated as a function of pH, biomass dosage, contact time, and temperature. The biosorption capacity of *Inonotus hispidus* for As(III) and As(V) was found to be 51.9 mg/g and 59.6 mg/g, respectively at optimum conditions of pH 6 for As(III) and pH 2 for As(V), contact time of 30 min and temperature of 20° C (Ahmet et al., 2009). The characteristics of As(III) biosorption from aqueous solution was studied using the green algae (*Ulothrix cylindricum*) biomass as a function of pH, biomass dosage, contact time, and temperature and its biosorption capacity was found to be 67.2 mg/g. At pH 2–6, the biosorption efficiency was increased by 80–96% and when pH was increased from 6 to 9, it decreased from 96% to 85%. The

maximum biosorption was found to be 98% at pH 6 (Tuzen et al., 2009). Biosorption of arsenic using algae as sorbent was investigated. Maximum adsorption capacities were estimated to be 45.2 mg/g (pH = 2.5), 33.3 mg/g (pH 4.5), and 28.2 mg/g (pH 6.5) indicating better adsorption at the lower pH. These values are high in comparison with other arsenic adsorbents reported. The kinetics was observed to be independent of pH during the first 120 minutes of adsorption (Hansen et al., 2006).

The tea fungus, a waste produced during black tea fermentation has been examined for its capacity to sequester the metal ions from ground water samples. FeCl<sub>3</sub> pretreated and autoclaved fungal mats removed 100% of As(III) and Fe(II) after 30 min of contact time and 77% of As(V) after 90 min of contact time. The results revealed that the FeCl<sub>3</sub> pretreated fungal mats could be used as an effective biosorbent for As(III) and As(V) (Murugesan et al., 2006).

A biomass derived from the plant *Momordica charantia* has been found to be very efficient in arsenite adsorption. An attempt was made to use this biomass for arsenite removal under different conditions. The parameters optimized were contact time (5–150 min), pH (2–11), concentration of adsorbent (1–50 g/L) and concentration of adsorbate (0.1–100 mg/L). It was observed that the pH had a strong effect on biosorption capacity. The biomass of *Momordica charantia* was found to be effective for the removal of As(III) with 88% sorption efficiency (Pandey et al., 2009). Char pine leaves (*Pinus roxburghii*) has also been considered for removal of As(V) ions from aqueous solutions. The influence of different sorption parameters such as the adsorbent dose, solution pH, contact time, agitation speed, and initial arsenic concentration were studied thoroughly to evaluate optimum conditions. Maximum adsorption was observed at pH 4.0 while equilibrium was achieved in 35 min. Maximum adsorption capacity was 3.27 mg/g (Shafique et al., 2012).

Dried plants have been used for removal of As(V) from aqueous solution under different experimental conditions. For this purpose, micro-particles of both *Calamirrhizoma* and *Withaniafrutescens* plants, were separately used without pre-treatment as natural adsorbents. Effect of various process parameters, such as adsorbent dose, contact time, initial As(V) concentration, temperature, and pH have been studied. The amount of As(V) adsorbed increases very rapidly up to about 120 min and slowly reaches saturation at about 180 min (Chiban et al., 2012).

As(III) and As(V) removal using orange juice residue and phosphorylated crosslinked orange waste has been studied. Orange waste contains cellulose, pectins, hemicellulose, chlorophyll pigments and other

low molecular weight compounds like limonene. The active binding sites for metals are thought to be the carboxylic groups of the pectins. The carboxylic group content of the original orange waste does not bind sufficient iron(III) to adsorb arsenic. Thus, the waste's cellulose content is phosphorylated in order to convert its abundant hydroxyl groups into phosphoric acid groups which have high affinity for ferric iron. The chemically modified adsorbents were then loaded with iron(III) in order to create a medium for arsenate and arsenite chelation. Arsenite removal was favored under alkaline conditions for both the gels. The orange waste gel showed some removal capability even at pH 7.0. Conversely, arsenate removal took place under acidic conditions at pH 2–3 and 2–6 for the cellulose gel and orange waste gel, respectively (Ghimire et al., 2006).

## 2.6 Arsenic Removal Using Nano-Particles

Recently, advances in nanoscience and nanotechnology have paved the way to the development of various nanomaterials for the remediation of contaminated water. Due to their high specific surface area, high reactivity, and high specificity, nanoparticles have been given considerable environmental attention as novel adsorbents of contaminants, such as heavy metals and arsenic, from aqueous solutions. Carbon nanotubes and nanocomposites, titanium-based nanoparticles, iron-based nanoparticles, and other metal-based nanoparticles are among the most widely used and investigated nanoparticles for the treatment of arsenic-contaminated water.

Studies suggest that the cupric oxide (CuO) nanoparticles effectively adsorb aqueous arsenic species. Batch adsorption kinetic experiments were conducted to determine the time course of uptake of arsenic by CuO nanoparticles (Reddy et al., 2013). In another study, waste red mud (bauxite residue) sample was evaluated for the synthesis of Fe<sub>3</sub>O<sub>4</sub> nanoparticles (NPs) in ammonia solution that can be used to remove As(V) from both synthetic and natural underground water samples. The results showed that synthesized Fe<sub>3</sub>O<sub>4</sub>-NPs from waste red mud have satisfactory magnetic properties and As(V) sorption capacity, especially at low equilibrium arsenate concentrations (Akin et al., 2012). Magnetite nanoparticles were used to treat arsenic-contaminated water. Because of their large surface area, these particles have an affinity for heavy metals by adsorbing them from a liquid phase. The results of the study showed that the maximum arsenic adsorption occurred at pH 2, with a value of approximately 3.70 mg/g for both As(III) and As(V) when the initial concentration of both arsenic species was maintained at 2 mg/L. The study showed that, apart from pH, the removal of arsenic from contaminated water also depends on the contact time, the initial concentration of arsenic, the phosphate concentration in the water and the adsorbent concentration (Chowdhury and Yanful 2011). Magnetic

magnetite nanoparticles are potential sorbents for arsenic removal in drinking water. The adsorption and desorption of arsenite and arsenate using magnetite nanoparticles and the effect of dispersion of the nanoparticles were investigated (Cong et al., 2005). The effect of Fe<sub>3</sub>O<sub>4</sub> particle size on the adsorption and desorption behavior of As(III) and As(V) was studied. The results show that the nanoparticle size has a dramatic effect on the adsorption and desorption of arsenic. As particle size is decreased from 300 to 12 nm the adsorption capacities for both As(III) and As(V) increases nearly 200 times (Mayo et al., 2007).

## 2.7 Alternative Technologies

Some alternative options have been applied in West Bengal and Bangladesh including clay filters, deep tube wells, dug wells, surface and rainwater harvesting and solar distillation. Solar distillation techniques use the sun's energy to evaporate water, which is then re-condensed. This process of evaporation and re-condensation separates all chemicals, including arsenic, from the water (USEPA, 2001). In recent years, the search for novel technologies for removal of arsenic in order to reduce the cost of operation, non-hazardous compounds and its applicability in remote and rural area has been done. Other than the conventional techniques, other handy technologies like bioremediation, foam flotation and solvent extraction can also be used for arsenic removal. A few of the most promising emerging technologies use UV radiation, solar radiation and/or biological processes (bacterial or plant action) for arsenite removal. For example, the conversion of arsenite surpasses 95% when UV or solar radiation is used in the presence of iron or sulphites (Zaw and Emnett, 2002)

### 2.7.1 Solar oxidation and removal of arsenic

SORAS is a simple method of solar oxidation of arsenic in transparent bottles to reduce arsenic content of drinking water (Wegelin et al., 2000). Solar oxidation and removal of arsenic is a simple method that uses irradiation of water with sunlight in PET or other UV-A transparent bottles to reduce arsenic levels from drinking water. The SORAS method is based on photochemical oxidation of As(III) followed by precipitation or filtration of As(V) adsorbed on Fe(III) oxides. The SORAS (*Solar Oxidation and Removal of Arsenic*) process has been used in the rural Andes regions in Latin America. It is based on the adsorption of As(V) onto iron oxides and hydroxides using UV radiation (Saalfeld and Bostick, 2009; Herbel and Fendorf, 2006) and the addition of citrate as a catalyst for the formation of oxidising radicals that allow the conversion of arsenite to arsenate.

Combination of solar oxidation with adsorption might be an applicable development towards alternative to arsenic removal. The goal would be to optimize the

SORAS process by incorporating complementary conventional techniques, thereby increasing its reliability.

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